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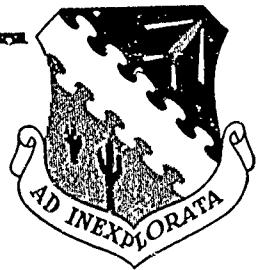
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AUTHORITY

ASD USAF ltr, 8 Feb 1974

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AD 900221
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**CATEGORY II SYSTEMS
FOLLOW-ON TESTS
OF THE
HH-53C HELICOPTER**

JOHN L. BARBAGALLO
Systems Engineer

EDWIN A. KOWAL
Captain, USAF
Systems Engineer

CLARK E. LOVRIEN, JR.
Major, USAF
Project Officer/Pilot

SYDNEY E. GURLEY
Major, USAF
Project Pilot

TECHNICAL REPORT No. 72-7
FEBRUARY 1972

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Wright-Patterson AFB, Ohio 45433.

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EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433



REPLY TO
ATTN OF ASD/SDQH 6-40 (Major Thompson/ech/54480/R&D 9-3/H-53)

SUBJECT ASD Addendum to FTC-TR-72-7, H-53 Salt Ingestion Tests

TO Recipients of FTC-TR-72-7

This report is a part of and should remain attached to FTC-TR-72-7 "Category II Systems Follow-On Tests of the HH-53C Helicopter". Paragraph numbers below correspond to the recommendations in the AFFTC Technical Report.

1 through 11. Concur with intent. ASD has initiated action to incorporate the required information in the aircraft flight manual. ASD will also establish a normalized temperature rise criteria (applicable to all engine conditions) equal to three times the percent power margin available prior to commencing salt water hover.

12 and 13. Concur with intent. ASD has initiated action to incorporate the required information in the aircraft flight manual.

14. Concur. ECP 7443 to correct this problem was given engineering approval by ASD. Procurement and retrofit action is the responsibility of WRAMA.

15. Concur. ASD has given engineering approval to ECP's to correct this problem. Procurement and retrofit action is the responsibility of WRAMA.

16. Concur, however engineering responsibility has been transferred to OOAMA. Any retrofit action is the responsibility of WRAMA.

17. Concur with intent if this is truly a problem. However, ASD is not aware of any in-service difficulties during four years of operation. In addition, engineering, procurement and retrofit action is the responsibility of WRAMA.

18. Concur, however this is a WRAMA responsibility.

19. Concur, if this becomes a problem in service. To date no operational problems have been reported. Engineering responsibility has been transferred to WRAMA and they are the organization to establish erosion limits if it becomes necessary.

FOR THE COMMANDER

William D. Eastman
WILLIAM D. EASTMAN, JR., Lt Col, USAF
Chief, Helicopter Program Office
Directorate of Combat Systems
Deputy for Systems

FTC-TR-72-7

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FOREWORD

This report presents results of the HH-53C follow-on systems tests requested through the Helicopter Program Division (SDQH), Aeronautical Systems Division. High altitude systems tests were conducted at Bishop, California, from 25 September to 16 November 1971 in conjunction with high altitude performance tests (reference 1). Salt water ingestion tests were accomplished at North Island Naval Air Station from 18 to 28 November 1971. Tests were conducted under authority of AFFTC Project Directive No. 71-24.

The authors wish to express appreciation to the personnel of North Island NAS for their cooperation in support of the salt water ingestion testing.

Foreign announcement and dissemination by the Defense Documentation Center are not authorized because of technology restrictions of the U.S. Export Control Acts as implemented by AFR 400-10.

Prepared by:



JOHN L. BARBAGALLO
Systems Engineer



EDWIN A. KOWAL
Captain, USAF
Systems Engineer



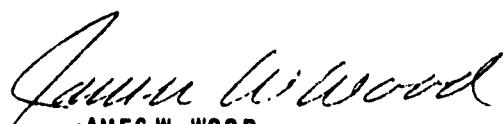
CLARK E. LOVRIEN, JR.
Major, USAF
Project Officer/Pilot



SYDNEY E. GURLEY
Major, USAF
Project Pilot

Reviewed and approved by:

8 FEBRUARY 1972



JAMES W. WOOD
Colonel, USAF
Commander, 6510 Test Wing



ROBERT M. WHITE
Brigadier General, USAF
Commander

ABSTRACT

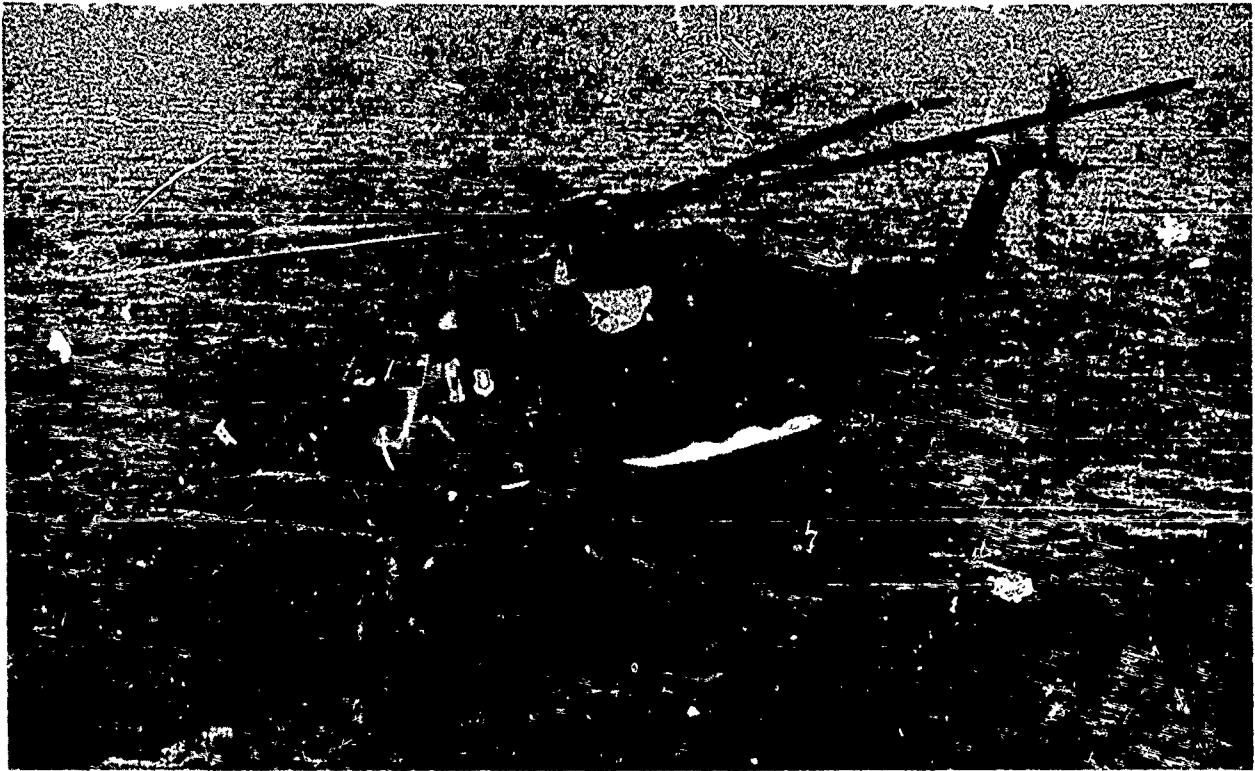
The HH-53C follow-on tests were conducted to identify the effects of salt water ingestion in regard to engine deterioration, to identify system deficiencies, and the effects of high altitude operation particularly as it affects the auxiliary power plant (APP). The more important findings were as follows: (1) salt water exposure can cause significant engine power deterioration; therefore, engine air particle separators should be used for protection; (2) the second stage hydraulic system can overheat with ambient temperature conditions as low as 50 degrees F; (3) the APP operation was adequate for high altitude conditions; (4) downwind hover caused ingestion of exhaust gases into the oil coolers resulting in oil overtemperature; (5) the aircraft brakes were inadequate at high altitude, high gross weight combinations which required running landings and takeoffs.

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list of abbreviations and symbols

<u>Item</u>	<u>Definition</u>	<u>Units</u>
AFCS	automatic flight control system	- - -
APP	auxiliary power plant	- - -
ASD	Aeronautical Systems Division	- - -
EAPS	engine air particle separator	- - -
EGT	exhaust gas temperature	deg C
KIAS	knots indicated airspeed	- - -
N_g	gas generator compressor speed	pct rpm
N_r	rotor speed	pct rpm
OAT	outside air temperature	deg C
PA	pressure altitude	feet
T_5	turbine inlet temperature	deg C



INTRODUCTION

General

The HH-53C test helicopter, USAF S/N 68-10354, was a rescue version of the H-53 and very similar to the CH-53C. Both the HH- and CH-53C's had the same major systems and therefore, these tests are valid for both models. The new test vehicle and test instrumentation were originally accepted by the Air Force at the Sikorsky Aircraft plant at Stratford, Connecticut, on 4 December 1969. Adverse weather (reference 2) and climatic laboratory (reference 3) tests were conducted by the Aeronautical Systems Division (ASD). After the climatic laboratory tests the responsibility for conducting Category II climatic tests was transferred to AFITC at Edwards AFB, California. Arctic climatic tests (reference 4), cold weather hover performance evaluation (reference 5), advancing blade-tip machmeter evaluation (reference 6) and icing tests (reference 7) were conducted at Eielson AFB, Alaska. Desert tests (reference 8) were conducted at the Naval Air Facility, El Centro, California. High altitude systems and performance tests were conducted at Bishop, California, from 25 September to 16 November 1971. The salt water ingestion tests were conducted from North Island Naval Air Station, San Diego, California, from 18 to 28 November 1971. The aircraft was returned to the Sikorsky Stratford plant for deinstrumentation and repair on 13 December 1971.

Aircraft Description and Instrumentation

The test helicopter, USAF HH-53C, S/N 68-10354 was manufactured by Sikorsky Aircraft Division of the United Aircraft Corporation, Stratford, Connecticut.

The HH-53C propulsion system consisted of two turboshaft T64-GE-7 engines designed to produce 3,925 shaft horsepower each under sea level standard day conditions. The engine air particle separators (EAPS), installed to cover the inlet of each engine, were designed to remove sand, dust, and other foreign particles from the engine inlet air, scavenge, and then eject these particles overboard. All-weather capability was provided by an automatic flight control system (AFCS), engine and windshield anti-icing systems, and instrument landing and navigation systems. The rescue helicopter was equipped with a hydraulic rescue hoist, strategically placed armor plating, armament consisting of three pintle-mounted 7.62mm miniguns, external auxiliary fuel tanks, and an aerial refueling system. The cargo compartment was equipped with two cargo winches, roller conveyors in the cargo compartment floor, cargo and litter tiedown facilities, and troop seat provisions. An auxiliary power plant (APP) provided a self-starting capability, power for cargo loading and unloading, and aircraft systems checkout while on the ground. The tricycle landing gear was retractable and a retractable tail skid provided tail rotor protection on landing.

The primary mission was search, location, and recovery of combat aircrew members. The secondary mission was delivery of supplies and troops to forward combat areas.

The HH-53C helicopter used during the follow-on tests was in standard configuration except for a modified tail rotor which provided approximately 4 degrees of additional pitch control beyond the existing standard. The test instrumentation described in reference 9 was used. This instrumentation consisted of a low speed digital airborne tape recording system which normally sampled each test parameter three times per minute and a photo-panel which was used to monitor selected system parameters.

Program Objectives

Tests were conducted to identify the effects of salt water ingestion in regard to engine deterioration, to identify systems deficiencies and the effects of high altitude operation, particularly as it affects the auxiliary power plant (APP). Specific test objectives were to:

1. Determine engine power deterioration due to salt water spray ingestion with and without the EAPS installed on the T64-GE-7 engines.
2. Investigate salt water spray patterns at hover heights ranging from 5 to 200 feet above the water.
3. Determine effects of wind velocity and sea state on salt water spray patterns.
4. Evaluate a second stage hydraulic system overtemperature problem.
5. Evaluate operation with increased engine torque and temperature limits.
6. Determine APP performance during ground operations at high elevations.
7. Investigate engine oil overtemperature conditions/limits during downwind hover.

TEST AND EVALUATION

Salt Water Ingestion

Test Method

The procedure in T.O. 1H-53(H)B-2-2 (reference 10) for determining engine power deterioration with and without EAPS on the T64-GE-7 engine was followed. Determination of power deterioration required test parameters of outside air temperature (OAT), power turbine inlet temperature (T_5), engine torque, rotor speed (N_r), pressure altitude (PA), and indicated airspeed in knots (KIAS). Evaluation of test results required the following additional test parameters: Gas generator compressor speed (N_g), hover height, wind velocity, and sea state. OAT, T_5 , engine torque and N_r were recorded on the photopanel and also monitored on standard cockpit instruments. The airspeed and PA were manually recorded from the standard cockpit instruments. A setting of 29.92 inches of Hg was used on the cockpit altimeters during all tests. N_g was recorded on the photopanel and monitored on cockpit instruments. The wind velocities at the test site were taken with a hand-held anemometer and a compass from a position outside the effects of the helicopter rotor wash or obtained from the Naval Air Station tower. Hover height (in feet) over the water was manually recorded from the radar altimeter. The sea state conditions were observed and noted using the U.S. Navy Hydrographic Office scale as noted in table I.

Table I
HYDROGRAPHIC OFFICE SEA STATE CODES

Sea State Code	Term and Height of Waves (ft)	Effects Observed at Sea	Effects Observed on Land
0	Calm, 0	Sea like mirror.	Calm; smoke rises vertically.
1	Smooth, less than 1	Ripples with appearance of scales; no foam crests.	Smoke drift indicates wind direction; vanes do not move.
2	Slight, 1-3	Small wavelets; crests of glassy appearance, not breaking.	Wind felt on face; leaves, rustle; vanes begin to move.
3	Moderate, 3-5	Large wavelets; crests begin to break; scattered whitecaps.	Leaves, small twigs in constant motion; light flags extended.

A test site was selected approximately 400 yards off shore with a Navy crash/rescue boat anchored in the vicinity. Photographic coverage of the salt water spray patterns and spray impingement on the aircraft were taken from the test aircraft, a support helicopter, the reference boat, and from the beach.

The helicopter was first flown over the test site at a gross weight of 35,000 pounds with EAPS installed on both engines. The initial hover height was 200 feet above the water. A descent was made to hover heights of 150, 80, 50, 30, 15, and 5 feet while observing spray patterns and the height at which salt spray first contacted the helicopter. All hover tests were made into the wind except as noted in a subsequent paragraph.

At each hover height a check was made to determine when the spray first appeared on the windshield.

The windshield and EAPS were at almost the same level on the aircraft; therefore, salt spray on the windshield indicated a definite impingement of salt spray on the EAPS and engine nacelle. This was confirmed through visual observation of the engine nacelles. Initially a 10-minute hover was made to monitor engine parameters T_5 , N_g , and torque for any indications of power deterioration. A single point power deterioration check per reference 10 was later evaluated and the time at this same hover height was increased to 30 minutes. To accurately determine power losses during the salt water ingestion tests, two and three point power deterioration checks in forward flight were frequently made per reference 10. This procedure allowed an accurate determination of power loss for a given set of hover conditions and time in the hover. From these periodic checks a time remaining until the engines would drop below the minimum allowable torque was projected. For test purposes the maximum allowable power loss was a reduction in initial torque to the minimum torque or reject line as established in reference 10.

To determine any differences in the rate of power deterioration when operating without EAPS, the helicopter was operated with the EAPS on only one engine under similar aircraft and environmental conditions as previously described. For flight safety one EAPS was left installed at all times.

Operations at a gross weight of 40,000 pounds were also flown to evaluate the effects of increased gross weight on the salt water spray pattern. To evaluate the effects of hovering in a position other than directly into the wind, a 360-degree turn was made at a slow rate and the impingement of spray on the aircraft was observed.

Standard engine washing procedures were followed after each flight. These procedures are presented in T.O. 1H-53(H)B-2-2 (reference 10) and involve the use of water and a cleaning solution (Rust Lik).

Analysis

The salt water ingestion tests consisted of nine flights totalling 13.2 flight hours. Table II contains a summary of the tests. Six flights were made with EAPS installed on both engines. On three flights the EAPS was installed only on the left hand engine (No. 1).

Many factors such as hover height, gross weight, salinity of the water, and concentration of the spray are variables in determining the rate of engine power deterioration when hovering over salt water. However, at a constant hover height, wind speed and wind direction were determined to be the most important factors controlling the rate of salt buildup in the engines and subsequent power loss. A 5-foot hover height was the minimum used during the tests to obtain the heaviest concentration of salt spray and still prevent the fuselage from contacting the water during the hover. While a 5-foot hover height was used for test purposes, it was not a realistic height for normal overwater hover operations (figure 1). If a low hover is required, a 10-foot height would be better for water-fuselage clearance and hover reference using objects in the water.

Table II
SALT WATER INGESTION TEST RESULTS

Flight	Configuration No. 1 Engine	Configuration No. 2 Engine	Sea State	Winds (kts)	Hover Heights (ft)	Time of Hover (min)	Reason for Test Ending and Results
1	EAPS ON	EAPS ON	3	8-15 8-15 8-15	15 10 5	15 15 30	Transmission warning lights came on. Investigation showed indications to be false.
2	EAPS ON	EAPS ON	1	3.5 5	5	15 20	Power deterioration checks showed negligible power change.
3	EAPS ON	EAPS OFF	2	10 7 7	20	15 15 5 5	13-percent torque loss on No. 2 engine. Negligible torque loss on No. 1 engine.
4	EAPS ON	EAPS OFF	1	2-5	5	57	Power deterioration checks showed negligible power change.
5	EAPS ON	EAPS OFF	3	8-12	5	19	9.5-percent torque loss on No. 1 engine. 25-percent torque loss on No. 2 engine.
6	EAPS ON	EAPS ON	2	5-6	5	29	Increased number of point power checks. Restricted to one hour flight time. 4-percent torque loss on No. 1 engine. 2.5-percent torque loss on No. 2 engine.
7	EAPS ON	EAPS ON	2	6	5	35	Gross weight of 40,000 lbs. Spray pattern wider in diameter. Restricted to 1 hour flight time. 19-percent torque loss on No. 1 engine. 10-percent torque loss on No. 2 engine.
8	EAPS ON	EAPS ON	2	9	10	35	Restricted to 1 hour flight time. 26-percent torque loss on No. 1 engine. 16-percent torque loss on No. 2 engine.
9	EAPS ON	EAPS ON	1	5	5	30	Restricted to 1 hour flight time. Negligible power loss.



Figure I Five-Foot Hover Height

Three flights were made in the environmental conditions of a sea state of one and winds ranging from zero to 5 knots. Some spray was ingested as the helicopter came to a hover. After becoming established in a 5-foot hover, the rotor downwash continued to blow the salt spray away from the helicopter and engine inlets. Under these conditions the engine inlets and the windshield remained dry. No measurable engine power deterioration was experienced under these conditions. Based on the results of the 57-minute flight 4 (table II) it was determined that hover operations at any altitude over salt water with wind conditions of 5 knots or less can be safely conducted for at least 2 hours without a complete loss of engine power margin. This applies with or without EAPS.

Four test flights were made with a sea state of two and light winds ranging from 5 to 10 knots. Two flights were made at a 5-foot hover, one at a 10-foot hover, and the remaining one at a 20-foot hover. With 5-to 7-knot winds at a 5-foot hover height, the spray pattern started to form a light spray on the windshield and engine inlets/EAPS. The increased gross weight on one flight produced a wider pattern of spray, but did not increase spray impingement on the aircraft. A moderate spray impinged on the windshield with 7- to 9-knot winds and required constant use of the windshield wipers.

In light to moderate wind conditions, salt spray being blown into the engines was minimized or eliminated by hovering downwind. However, hovering downwind will result in increased pilot workload, and the possibility of exceeding engine temperature limits. During tests flown at 38,000 pounds gross weight, the power required and the associated T_5 were below the maximum continuous limits for the -7 engine.

Two test flights were made with a sea state of three and winds of 8 to 15 knots. Both flights (flights 1 and 5, table II) were characterized by a spray pattern that engulfed the helicopter while in a 5-foot hover. When hovering directly into a wind of 8 to 15 knots, an engine power loss of 25 percent torque was experienced when the EAPS was not installed. With EAPS installed, under the same conditions, the power deterioration rate was much slower and the useful hover time was increased. Even with EAPS installed, a low hover height in wind conditions (over 5 knots) which produce moderate to heavy spray on the windshield (requiring constant use of windshield wipers) could result in a complete loss of power margin in as little as 20 minutes.

During 20-foot hover tests (flight 3, table II), with a sea state of two and a 7-knot headwind, the No. 2 engine (without EAPS) experienced an approximate 13-percent decrease in power after a hover time of 40 minutes. The No. 1 engine (with EAPS) had a negligible power loss during the same period. This also indicated that hovering over salt water with EAPS installed increased allowable hover time. Hovering over salt water should always be accomplished with EAPS installed. (R1)¹

Frequent power deterioration checks were made before and after hovering over salt water and at any time a noticeable power loss was apparent while in the hover. The normal maximum allowable power loss was a reduction in initial torque to the minimum torque or reject line as established

¹Boldface numerals preceded by an R correspond to the recommendation numbers tabulated in the Conclusions and Recommendations section of this report.

in reference 10. For test purposes one engine without EAPS installed was allowed to drop 15 percent below the normal minimum torque allowed. No compressor stalls were experienced in this case; however, there was no guarantee that there was any stall margin remaining once the engine torque had deteriorated below the minimum. For this reason, salt water hover operations should be terminated once either engine has deteriorated below the minimum allowed by reference 10. (R 2)

Various hover heights from 5 to 200 feet (wheel heights) above the water were evaluated. Spray patterns and the height at which salt spray first contacted the helicopter were noted (figure 2). With wind speeds of 5 knots or less, a very light spray was normally encountered at hover heights as high as 60 to 70 feet. At lower hover heights, the increased rotor wash on the water surface blew the spray away from the aircraft. With wind speeds over 5 knots, the increased wind speed tended to blow the spray under the aircraft and spray was encountered at lower hover heights. For example, on Flight 1 with a wind speed of 15 knots, spray was not encountered until a hover height of 20 feet was reached. As previously pointed out, the best indicator was always spray on the windshield. The amount of spray observed on the windshield and the necessity of using windshield wipers to maintain visibility were immediate indications of spray ingestion into the engine. During the tests, light to moderate spray required use of the windshield wipers and caused engine power loss even with EAPS installed. Generally the heaviest spray concentration was encountered at the lowest hover height (holding all other factors constant). It is recommended for normal salt water hover operations that the helicopter be hovered high enough so that no spray is noted on the windshield to prevent significant salt spray ingestion with subsequent engine power loss. (R 3)

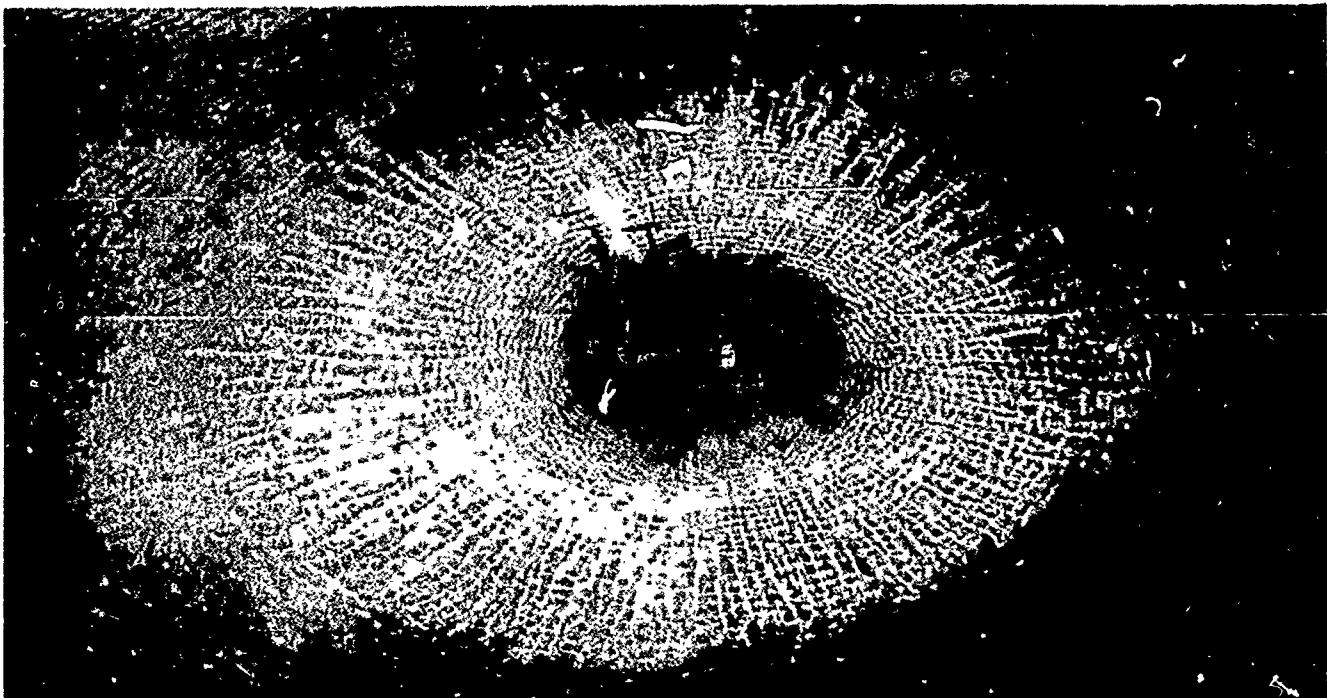


Figure 2 Spray Pattern

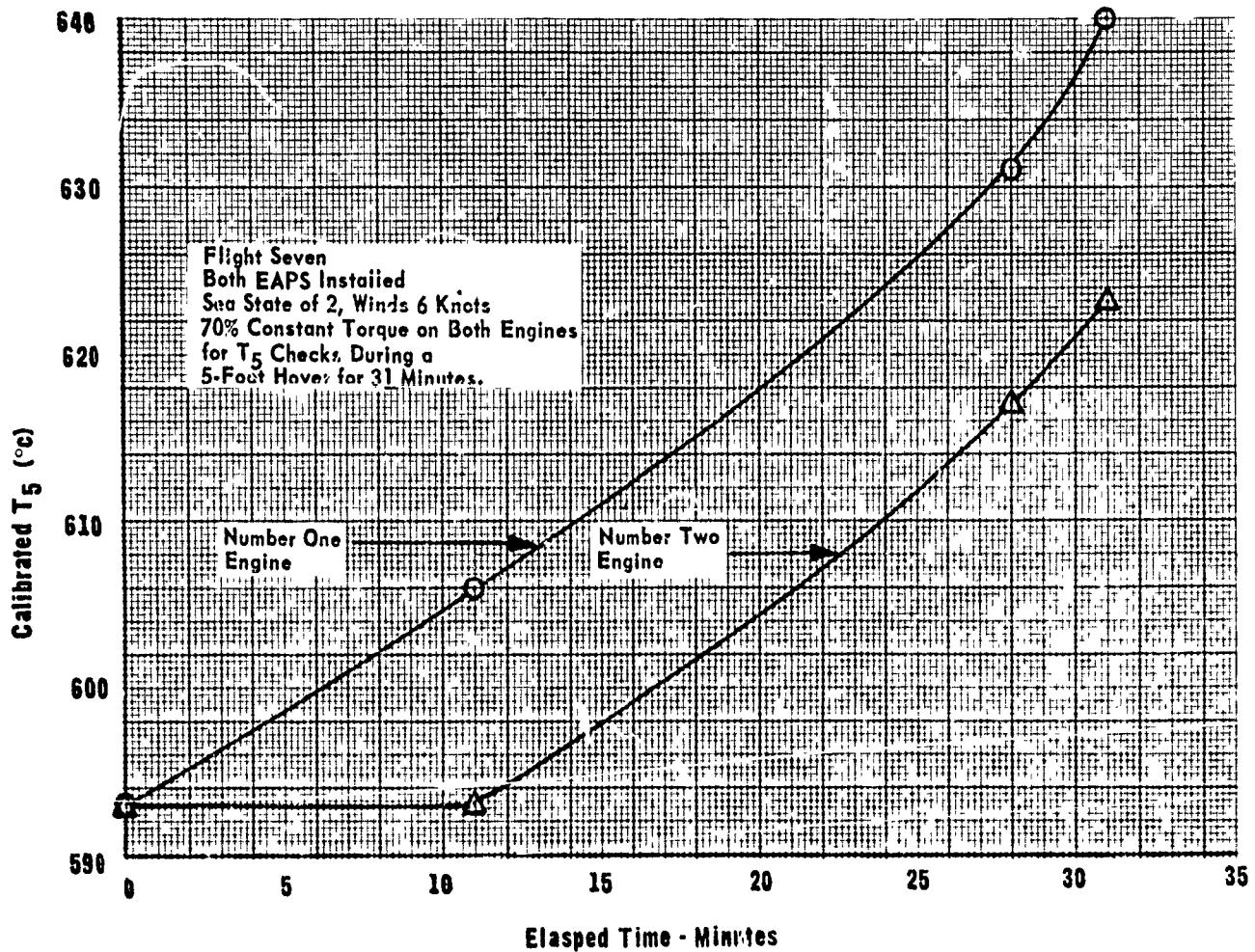


Figure 3 Effect of Salt Spray Ingestion on Power Turbine Inlet Temperature

To hover safely over salt water, it was determined that a single point power deterioration check should be made in forward flight before entering the hover. Then, while in the hover, the rise in T_5 should be checked periodically with the engine operating at the initial hover torque setting. To accomplish this, a given hover height was established first, the power set, and the corresponding torque and T_5 noted. To maintain a constant hover height as fuel was burned off, the torque was reduced. At frequent intervals, any rise in T_5 was determined by setting one engine at a time to the original hover torque and noting the corresponding T_5 . By using this technique, an accurate time history of the increase in T_5 was obtained, giving an indication of the rate and severity of the power deterioration due to the salt water ingestion. The engines used during these tests had an approximate 10-percent performance margin when clean. For these engines, it was observed that a 30-degree C rise in T_5 at a constant torque setting corresponded to an almost complete loss of this margin. This rise in T_5 did not occur at a constant rate but at an increasing rate as hover time increased. Figure 3 shows the characteristics of the rise in T_5 due to salt water ingestion with respect to hover time. Figure 4 shows the characteristics of the loss in torque due to salt water

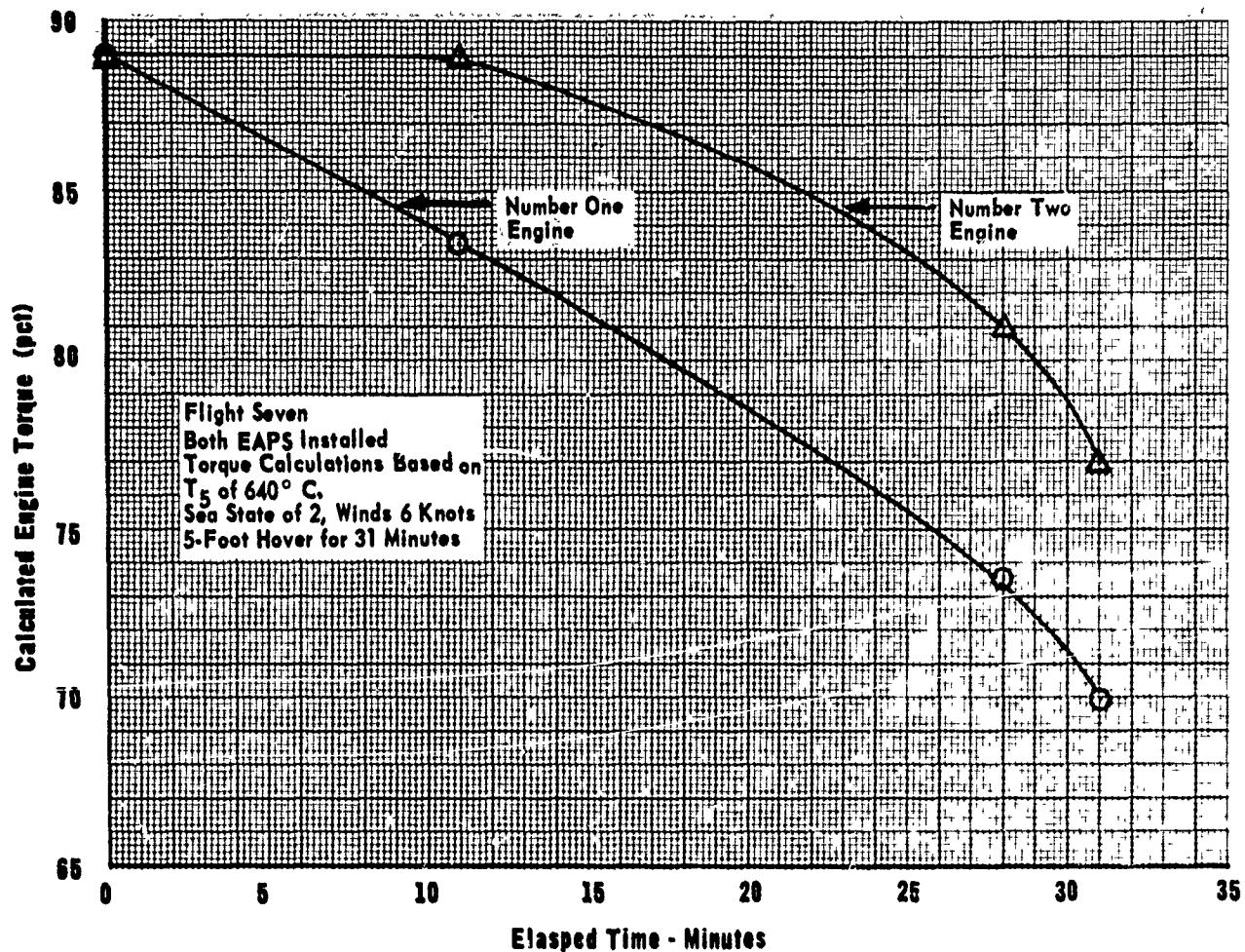


Figure 4 Effect of Salt Spray Ingestion on Engine Torque

ingestion with respect to hover time. These figures show data taken with EAPS installed on both engines. It was also observed, during winds of 5 to 6 knots, that the counterclockwise rotation of the main rotor blades caused more spray to impinge on the left side of the aircraft. This would indicate that the left hand engine ingested more salt spray over a given period of time than the right hand engine and explains the more rapid rise in T₅ for the left hand engine.

For salt water hover operations, the power deterioration check procedures used during these tests were found to provide an accurate assessment of engine power. A single point power deterioration check should be made per T.O. 1H-53(H)B-2-2 (reference 10) prior to entering the hover. If either engine does not meet the minimum torque requirements, hover operations should not be performed. If the engines demonstrate sufficient power margin, T₅ (at the initial hover torque setting) should be monitored throughout hover operations. A rise of 30 degrees C in T₅, as observed using this method, should result in termination of hover operations followed by a single point power deterioration check in forward flight. If either engine has dropped below the minimum torque, the salt

water hover operations should be terminated. If both engines are still above the minimum torque, hover operations may be continued. Caution must be used if some deterioration has been noted, because subsequent hover operations may accelerate the rate of power loss. The No. 1 engine is more critically exposed and should be more closely monitored. (R 4, R 5, R 6, R 7, R 8, R 9)

Water/Rust Lik washing procedures were used after each flight during the tests; in all cases original power was restored to both engines. Water/Rust Lik washing procedures in T.O. 1H-53(H)B-2-2 (reference 10¹) should be accomplished immediately following operations over salt water to remove deposits, reduce severity of corrosion, and to regain any lost power. (R 10)

Flight Manual (reference 11) instructions incorporating recommendations 1 through 10 are proposed to read as follows: (R 11)

"Hovering over salt water at an altitude which causes concentrated spray ingestion into the engine inlets results in gradual power deterioration and eventual reduction of compressor stall margin. Since the effective hover time over salt water can be increased significantly with the EAPS installed, hover over salt water without the EAPS installed is not recommended. Normal salt water hover operations should be conducted high enough so that no spray is noted on the windshield to prevent salt spray ingestion with subsequent engine power loss. With or without the EAPS installed, the following procedure should be used. Make a single point power deterioration check on each engine prior to commencing salt water hover operations. If either engine does not meet the minimum torque requirements, salt water hover operations should not be attempted. For engines in good condition, the torque will generally be 10 to 12 percent above the minimum. After a hover is established, note the torque and T₅ required for each engine for a given hover height. As a hover operation progresses, note any rise in T₅. An accurate check can be made by setting each engine, one at a time, to the original torque, and noting the increase in T₅. Due to rotor wash, engine No. 1 is more critical and should be closely monitored. If a T₅ rise of 30 degrees is noted in either engine, terminate the hover and make a single point power deterioration check in forward flight. If either engine has dropped below the minimum torque, the salt water hover operations should be terminated. If both engines are still above the minimum torque, hover operations may be continued. Caution must be used if some deterioration has been noted because subsequent hover operations may accelerate the rate of power loss. Generally, a 30 degree T₅ rise will result in a 10 percent torque loss. The engines should be washed prior to continuing operations. Water wash/Rust Lik procedures in T.O. 1H-53(H)B-2-2 must be performed whenever operations have been conducted near salt water to reduce the severity of subsequent corrosive attack and to regain lost power/stall margin."

Second Stage Hydraulic System Overheat

During the desert test (reference 8), the second stage hydraulic system overheated during ground operations. Ambient temperatures were in excess of 100 degrees F (38 degrees C). The hydraulic system was isolated from the automatic flight control system (AFCS) which decreased the cooling potential to some degree during these tests.

Further testing was accomplished to determine system operating temperatures at lower ambient air temperature. All second stage hydraulic system working components were replaced after the referenced overheat conditions. The system was operated for 1 hour and 12 minutes to assure temperature stabilization. The AFCS No. 1 was "ON" at the time which routed the hydraulic fluid through additional plumbing and possibly increased the fluid cooling. Ambient air temperature was 32 degrees F (0 degree C) during these tests. The fluid temperature stabilized at 107 degrees C (225 degrees F) measured at the hydraulic pump inlet.

There was no published temperature limit for this system. A reasonable limit of 135 degrees C was assumed since this was the operating temperature for actuation of the utility hydraulic system temperature caution light (reference 11, Section III). While the system was 28 degrees C below this limit for the test conditions, system overheat could be anticipated with ambient temperatures as low as 50 to 70 degrees F (10 to 21 degrees C), depending on operating time. This test substantiated R-18 and R-19 of the desert test report (reference 8) which recommended installation of an oil cooler and an overtemperature warning system.

Increased Engine and Transmission Power Capability

During the follow-on testing, engines were operated at increased power (T₅ and torque). This required operation of the engines and main transmission beyond the T.O. limits existing at that time. The purpose of the increased thrust levels was to permit tail rotor performance testing. Table III presents the increased power used, and the results of the performance tests are given in reference 1. No significant effects, such as component failures or overheat conditions, could be attributed to the increased engine power.

Table III
ENGINE AND TRANSMISSION LIMITS

I. Engine Limits		Power Turbine Inlet Temperature (T ₅)		
	Gas Generator Speed (pct N ₁)	Existing Limit (deg C)	Test Limit (deg C)	Time Limit (min)
Maximum power	100	721	750	10
Military power	100	699	746	30
Maximum continuous power	100	671	704	None

II. Transmission Torque Limits			
	Existing Limit	Test Limit	Time Limit
Maximum	100	118	10
Maximum continuous	80	100	None

With the increased power, the aircraft could be operated at higher altitudes and heavier loads. For example, a normal takeoff and landing could be accomplished up to approximately 9,500 feet pressure altitude (PA) at the maximum gross weight of 42,000 pounds, an increase of about 3,000 feet from its capability when using existing engine and transmission limits.

Engine Oil Overtemperature Condition

During the desert test (reference 8), engine oil overtemperature occurred during downwind hover. These overtemperature conditions occurred at high ambient temperatures of 104 degrees F (40 degrees C) or higher.

During the follow-on phase, a test was conducted to see if the condition could be duplicated at lower ambient temperature conditions. A downwind hover was performed at 46 degrees F (8 degrees C) with a 15-knot wind. Under these conditions, the engine oil overtemperature also occurred. As in the desert tests, the temperature did not stabilize, and was still rising when the test was terminated.

It is concluded that a downwind hover condition caused engine exhaust gases to be ingested into the coolers, degrading their effectiveness, and resulting in an overtemperature condition.

As recommended in the desert test report (reference 8) a "caution" should be placed in the Flight Manual concerning the expected overtemperature in a downwind hover. However, it should also include the statement that an overtemperature must be expected regardless of the ambient temperature. (R12)

Auxiliary Power Plant High Altitude Operation

During early HH-53C testing, it became apparent that the APP was marginal in power. Tests were conducted to determine if the APP performance could be improved by altering procedures or limits. Satisfactory cold weather operation in the arctic tests (reference 4) was obtained by using a fuel control adjustment procedure. Satisfactory operation in high ambient temperatures during the desert ground testing (reference 8) was obtained by avoiding exhaust ingestion caused by downwind conditions.

Inflight operation, however, during the desert tests (reference 8), indicated that a high altitude condition (above 5,000 feet PA) would cause an overheat of the APP during engine starts (the starter is powered by the APP). The condition was improved by eliminating all other power requirements from the APP during engine starts, but overheat still occurred. The inflight testing was not considered conclusive because of the possibility that rotor wash caused exhaust ingestion (previously found to be a cause of the overheat). In addition, typical APP operation requires the aircraft to be on the ground with rotors stationary.

For the follow-on program a more realistic series of APP tests was conducted at a high altitude test site (Coyote Flats near Bishop, California) having a field elevation of approximately 10,000 feet. The APP maximum continuous exhaust gas temperature (EGT) limit was 560 degrees C. The transient limit was 10 seconds between 560 degrees C and 648

degrees C. The maximum limit was 648 degrees C. The tests were based on the most severe condition of engine starts.

Test results are shown in table IV. Downwind conditions and other loads on the APP had to be avoided to prevent an APP EGT overtemperature condition. It was not necessary to adjust the fuel control for the high altitude operation (it was last adjusted at approximately sea level field elevation). Fourteen successive engine starts were made using APP power with only two unsatisfactory starts. One of the unsatisfactory starts was made in a downwind condition which caused an APP overheat. The second unsatisfactory start resulted in an APP EGT of 570 degrees C; however, insufficient data were available to verify that an actual overheat (10 seconds above 560 degrees C) occurred. The APP was capable of satisfactory high altitude operation providing that downwind conditions are avoided and that there are no other loads imposed on the APP during engine starts using APP power. It is not necessary, nor is it recommended, to change the existing APP EGT limits. The appropriate sections of the Flight Manual should be revised to mention the precautions for high altitude operation; that is, to avoid downwind conditions and other loads on the APP during engine starts. (R 13)

Table IV
MAXIMUM APP EGT DURING ENGINE STARTS

Flight No.	Date (1971)	Pressure Altitude (ft)	OAT (deg C)	Density Altitude (ft)	APP EGT (deg C)
4	2 Oct	9,600	6	10,800	506
5	3 Oct	9,560	8	10,900	557
5	3 Oct	9,550	7	10,800	530
6	4 Oct	9,460	19	12,000	512
12	11 Oct	9,460	20	12,100	518
16	19 Oct	9,650	20	12,600	522
17	20 Oct	9,660	12	11,500	490
18	21 Oct	9,600	7	10,900	468
18	21 Oct	9,600	7	10,900	570*
20	22 Oct	9,520	16	11,700	480
21	23 Oct	9,910	4	11,000	490
27	7 Nov	9,680	12	11,500	600**
28	8 Nov	9,740	4	10,700	555
32	16 Nov	9,860	4	10,900	500

* Insufficient data to determine if overheat occurred.

** Overheat caused by 5-knot tail wind.

Functional Deficiencies

All functional deficiencies listed below were previously identified and reported except for the leak in the utility/landing gear hydraulic system.

Winch Pump Shutoff Valve

During the salt water ingestion tests it was necessary to motor the engines for as long as 5 minutes to accomplish the required washing after salt water exposure. This required operation of the winch pump which provided hydraulic motoring power. This continuous energizing of the winch pump shutoff valve (P/N HP 925300-6) caused valve warpage and subsequent jamming in the closed position. The ambient air temperature was approximately 70 degrees F. After the valve cooled it operated normally, but continued use in this manner caused deterioration, i.e., failure after a shorter period of time. The valve had failed in a similar manner during the desert test program when the ambient temperature was 110 degrees F. It was concluded in the desert test report (reference 8) that the high operating temperature of the solenoid contributed to the valve failure, and it was recommended that further research be conducted to correct the deficiency as soon as possible. This conclusion and recommendation are still valid. (R 14)

Main Rotor Head

The main rotor head sleeve and spindle seal assemblies leaked while the helicopter was undergoing adverse weather tests at Wright-Patterson AFB (reference 2), while undergoing climatic tests in the climatic laboratory at Eglin AFB (reference 3) and during the arctic tests at Eielson AFB, Alaska (reference 4). In addition, spindle reservoir leakage occurred during the climatic laboratory tests and during the desert tests at El Centro Naval Air Facility (reference 8). These same failures occurred during and immediately following the salt water ingestion tests. Leaks from the sleeve and spindle seals previously occurred at low temperatures (0 degrees F and lower); however, this time two rotor heads leaked at relatively mild temperatures (20 degrees F to 75 degrees F). One of the two rotor heads was the same one installed at Eielson AFB during the arctic tests and had accumulated approximately 200 hours (including operation during the desert tests). The other was newly installed and started to leak after less than 20 hours of operation; the leaks were slight but persistent, and continued until the aircraft was transferred from AFFTC to Sikorsky, at which time the rotor head had approximately 30 hours of operation.

The rotor head lubrication system has a low service life especially during cold weather operation. A design change should be accomplished to correct this deficiency. (R 15)

Wheel/Brake Assembly

Following the desert test (reference 8) it was discovered that the wheel/brake assembly (P/N 3-1179-1) was marginal and probably inadequate. An inspection revealed that the bolt holes in the torque bar (P/N 252-110, reference 12, Fig. 2-26) were elongated and the wheel was cracked at the location where one of the brake blocks was mounted. (UR, AFFTC R71-137, 12 August 1971, was submitted).

The increased engine power capability used during the high altitude tests resulted in the use of high gross weight. This higher gross weight, combined with high altitudes and running landings, required increased braking. Under these conditions, wheel/brake assembly failures again occurred, and it was concluded that the wheel/brake assembly was inadequate for the increased requirements. The wheel/brake assembly should be strengthened to allow use of the improved operational capability. (R 16)

Tail Rotor Gust Locks

During the arctic tests, the tail rotor gust locks froze in the unlocked position and then released when defrosted. During the desert tests one tail rotor gust lock stock in the unlocked position apparently due to sand exposure. During the follow-on high altitude tests, two more stuck in the unlocked position due to exposure to soil dust from rotor wash when near the ground. The remaining gust lock was partially stuck and worked intermittently. The gust locks were still in this condition (three stuck and one partially stuck) at the end of the AFFTC tests. The tail rotor gust locks are much too susceptible to sticking from exposure to freezing moisture or fine material. The gust locks should be modified to correct this deficiency. (R 17)

Utility/Landing Gear Hydraulic System

During the course of the follow-on testing, an unidentifiable and persistent hydraulic leak occurred in the utility hydraulic system. The leak occurred only in flight, and the only abnormal indication was an "isolation valve open" light illuminating on the cockpit advisory panel. The leak depleted the utility system causing serious pressure fluctuation in flight. This condition was serious enough to warrant termination of flight.

Prolonged investigation eventually revealed two simultaneous failures:

1. A leak in the landing gear control valve located in the utility hydraulic system manifold assembly. This leak was caused by a cap seal leak. The cap seal was a ball spring retainer cap seal of the landing gear control valve. The cap seal could not be replaced as a field maintenance operation. To do so would cause defective operation of the landing gear control valve.
2. A failure of the isolation valve relay. One function of this relay was to close the isolation valve and isolate the utility hydraulic system from the landing gear after the landing gear was retracted. Failure of the relay allowed the isolation valve to remain open causing constant utility system pressure to remain on the upside of the landing gear control valve when the landing gear was retracted. This resulted in a constant leak in flight. It was not determined whether the safety mechanical backup for the isolation valve (designed to close at 2,000 psi) actuated.

Although these were considered random failures, operational fleet failures should be monitored to identify possible poor service life or unreliability of these components. (R 18)

Rotor Blade Erosion

The rotor blades were badly eroded from exposure to sand and soil during the desert test (reference 8) and high altitude test (reference 1). Although the blades were apparently still serviceable and were used during the follow-on tests, there was no information available to identify permissible erosion. Permissible erosion limits for the rotor blades should be established. (R 19)

CONCLUSIONS AND RECOMMENDATIONS

Salt Water Ingestion

General

The salt water ingestion tests demonstrated that the HH-53C could safely accomplish hover missions over salt water. The main concern, and the primary objective of the test, was in regard to engine deterioration when subjected to salt spray. The EAPS provided protection for the engines and decreased the rate of engine power deterioration. With EAPS installed and using a hover height that would not result in spray on the windshield, the HH-53C could be safely hovered for an indefinite period over salt water.

Results and Analysis

At a constant hover height, wind speed and wind direction were the most important factors controlling the rate of salt buildup in the engines and subsequent power loss. If the wind speed was 5 knots or less, (negligible spray), hover operations could be conducted at any hover height for at least 2 hours without complete loss of power margin. If the wind speed was over 5 knots, producing moderate to heavy spray, a low hover height could subject the engines to salt buildup that could result in complete loss of power margin in as little as 20 minutes even with EAPS installed. Hovering downwind would eliminate or minimize salt spray being ingested into the engines. Hovering downwind, however, would result in increased pilot workload, and the possibility of exceeding temperature limits. Increasing the gross weight produced a wider pattern of spray, but did not increase spray impingement on the aircraft. If a low hover was required, a 16-foot wheel height would be better for adequate water-fuselage clearance and hover reference (using objects in the water).

Hovering with EAPS installed under the same conditions as without EAPS installed decreased power deterioration rate and increased useful hover time.

1. Hovering over saltwater should always be done with EAPS installed (page 6).

No compressor stalls were experienced when the engine torque was allowed to go 15 percent below the normal minimum torque allowed per T.C. 1H-53(H)B-2-2 (reference 10). There was no guarantee that there was

any stall margin remaining once the engine torque had deteriorated below this minimum.

2. Salt water hover operations should be terminated once either engine has deteriorated below the minimum allowed by T.O. 1H-53(H)B2-2 (page 7).

Salt water spray impingement on the engine EAPS/inlet occurs at the same time as spray appears on the windshield. The heaviest spray concentration is encountered at decreasing hover height (holding all other factors constant).

3. To prevent significant salt spray ingestion with subsequent engine power loss, normal salt water hover operations should be conducted high enough so that no spray is noted on the windshield (page 7).

For salt water hover operations, the power deterioration check procedures used during these tests were found to provide an accurate assessment of engine power.

4. A single point power deterioration check should be made in accordance with T.O. 1H-53(H)B-2-2 (reference 10) prior to entering hover operations over salt water (page 10).
5. If either engine does not meet the minimum torque requirements specified in T.O. 1H-53(H)B-2-2 (reference 10), salt water hover operations should not be performed (page 10).
6. During salt water hover operations, engine T₅ should be monitored throughout the hover; engine T₅ should be checked with the engine at its initial torque setting (page 10).
7. A rise of 30 degrees C in T₅ should result in termination of salt water hover operations until the engine torque level can be determined by a single point engine power deterioration check (page 10).
8. If either engine drops below the minimum torque specified in T.O. 1H-53(H)B-2-2 (reference 10), salt water hover operations should be terminated (page 10).

During winds of 5 to 6 knots, the counterclockwise rotation of the main rotor blades causes more spray to impinge on the left side of the aircraft where No. 1 engine is located.

9. No. 1 engine appeared to be the more critically exposed and should be more closely monitored during hover operations over salt water (page 10).

Engine water/Rust Lik washing procedures restore original power after salt water hover operations.

10. Water/Rust Lik washing procedures in T.O. 1H-53(H)B-2-2 should be accomplished immediately following operations over salt water to remove deposits, reduce severity of corrosion, and to regain any lost power (page 10).

11. The Flight Manual (reference 11) instructions should be revised to incorporate recommendations 1 through 10 as proposed on page 10 of this report.

Other Tests

Second Stage Hydraulic System Overheat

Overheat of the second stage hydraulic system could be anticipated with ambient temperatures as low as 50 to 70 degrees F. The test of the second stage hydraulic system substantiated R 18 and R 19 of the desert test report (reference 8) which recommended installation of an oil cooler and an overtemperature warning system.

Increased Engine and Transmission Power Capability

No significant effects, such as component failures or overheat conditions, could be attributed to the increased engine power used during these tests.

Engine Oil Overtemperature Condition

Downwind hover caused exhaust gases to be ingested into oil coolers, degrading their effectiveness and resulting in an overtemperature condition.

12. As recommended in the desert test report (reference 9), a CAUTION should be placed in the Flight Manual concerning the expected overtemperature in a downwind hover. However, it should further include the statement that an overtemperature should be expected regardless of the ambient temperature (page 12).

APP High Altitude Operation

Although marginal in power, the APP was capable of providing satisfactory operation at high altitude if downwind conditions were avoided and no other loads were imposed on the APP during engine starts using APP power. The current limits for the APP should be retained.

13. The appropriate sections of the Flight Manual should be revised to mention the APP high altitude precautions; that is, to avoid downwind conditions and other loads on the APP during engine starts (page 13).

Functional Deficiencies

Winch Pump Shutoff Valve

The high operating temperature of the winch pump shutoff valve solenoid contributed to the valve failure.

14. The winch pump shutoff valve failure problem should be corrected as soon as possible (page 14).

Main Rotor Head

The rotor head lubrication system has a low service life especially during cold weather operation.

15. A design change should be made to increase service life of the rotor head lubrication system (page 14).

Wheel/Brake Assembly

The aircraft wheel brakes were inadequate for the expanded operational capability realized from increased engine power.

16. The wheel/brake assembly should be strengthened to allow use of the improved operational capability (page 15).

Tail Rotor Gust Locks

The tail rotor gust locks are much too susceptible to sticking due to exposure to freezing moisture or fine material.

17. The gust locks should be modified to correct a susceptibility to sticking due to exposure to freezing moisture or fine particles (page 15).

Utility/Landing Gear Hydraulic System

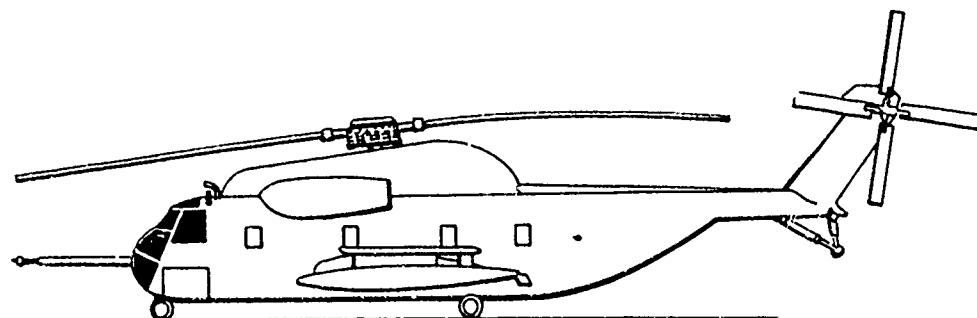
The failure of a cap seal on the utility hydraulic system manifold assembly, combined with a failure of the isolation valve relay, caused a utility hydraulic system leak condition. These were considered random failures.

18. Operational fleet failures should be monitored to identify possible poor service life or unreliability of these components (page 15).

Rotor Blade Erosion

The rotor blades were badly eroded from exposure to abrasive particles.

19. Permissible erosion limits for the rotor blades should be re-established (page 16).



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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body, of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Flight Test Center Edwards Air Force Base, California		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP N/A
3. REPORT TITLE Category II Systems Follow-On Tests of the HH-53C Helicopter		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final		
5. AUTHOR(S) (First name, middle initial, last name) John L. Barbagallo, et al.		
6. REPORT DATE February 1972	7a. TOTAL NO. OF PAGES 20	7b. NO. OF REFS 12
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) FTC-TR-72-7	
b. PROJECT NO. c. Project Directive 71-24	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) N/A	
d.		
10. DISTRIBUTION STATEMENT Distribution limited to U.S. Government agencies only (test and evaluation), January 1972. Other requests for this document must be referred to ASD (SDQH), Wright-Patterson AFB, Ohio 45433.		
11. SUPPLEMENTARY NOTES N/A	12. SPONSORING MILITARY ACTIVITY 6510 Test Wing Edwards AFB, California	

13. ABSTRACT

The HH-53C follow-on tests were conducted to identify the effects of salt water ingestion in regard to engine deterioration, to identify system deficiencies, and the effects of high altitude operation particularly as it affects the auxiliary power plant (APP). The more important findings were as follows: (1) salt water exposure can cause significant engine power deterioration; therefore, engine air particle separators should be used for protection; (2) the second stage hydraulic system can overheat with ambient temperature conditions as low as 50 degrees F; (3) the APP operation was adequate for high altitude conditions; (4) downwind hover caused ingestion of exhaust gases into the oil coolers resulting in oil overtemperature; (5) the aircraft brakes were inadequate at high altitude, high gross weight combinations which required running landings and takeoffs.

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
HH-53C helicopter systems						